

## SETI AT X-RAY ENERGIES - PARASITIC SEARCHES FROM ASTROPHYSICAL OBSERVATIONS

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(Accepted 1997 Journal of the British Interplanetary Society, Vol. 50, No. 7, p. 253 - 257)

## ABSTRACT

If a sufficiently advanced civilization can either modulate the emission from an X-ray binary, or make use of the natural high luminosity to power an artificial transmitter, these can serve as good beacons for interstellar communication without involving excessive energy costs to the broadcasting civilization. In addition, the small number of X-ray binaries in the Galaxy considerably reduces the number of targets that must be investigated compared to searches in other energy bands. Low mass X-ray binaries containing neutron stars in particular are considered as prime potential natural and artificial beacons and high time resolution (better than 1ms) observations are encouraged. All sky monitors provide the capability of detecting brief powerful artificial signals from isolated neutron stars. New capabilities of X-ray astronomy satellites developed for astrophysical purposes are enabling SETI in new parameter regimes. For example, the X-ray Timing Explorer satellite provides the capability of exploring the sub-millisecond region. Other planned X-ray astronomy satellites should provide significantly improved spectral resolution. While SETI at X-ray energies is highly speculative (and rather unfashionable) by using a parasitic approach little additional cost is involved. The inclusion of X-ray binaries in target lists for SETI at radio and other wavebands is also advocated.

*Subject headings:* extraterrestrial intelligence - X-rays:(stars) - stars: neutron - binaries

## 1. INTRODUCTION

While some estimates of the number of advanced civilizations in the Galaxy are large (e.g.  $10^6$  [1]) others suggest that if advanced civilizations exist they should be in the solar system given the short time required for a civilization to colonize the entire Galaxy compared to its age. Hence, as there appears to be no reliable evidence of extra-terrestrials within the solar system, these authors conclude that there is no such life in the entire Galaxy ("Fermi paradox", [2, 3]). Yet others, however, (e.g. Brin 1983 [4]) consider numerous factors that may mitigate this apparent paradox.

The discovery of extra-solar planets [5] together with possible fossil evidence of early life on Mars [6] gives hope that life may be common. However, evolutionary arguments (e.g. Mayr, 1995 [7]) suggest that, even if life is common, *intelligent* life may still be rare.

Despite these attempts to estimate the number of advanced civilizations that exist in the Galaxy, the only experimentally valid way to determine whether extraterrestrial intelligent life exists is to try and find it. The Search for Extraterrestrial Intelligence (SETI) has, to date, almost exclusively concentrated on narrow band radio signals. Principal amongst these searches have been the SERENDIP series [8], META/BETA [9], and Project Phoenix/HRMS [10]. While radio signals are certainly extensively used by human civilization for communication, given that we know nothing about how an advanced Extraterrestrial Civilization (ETC) might attempt to communicate, it is suggested here that it is too restrictive to investigate only narrow portions of the electromagnetic spectrum. In particular, building on the work of Fabian [11], it is considered whether X-ray emission might profitably be used by a "benevolent" ETC at-

tempting to communicate with other intelligence in the Galaxy and how we might detect such signals if they exist. Although a limited optical search is underway [12] this is viewed as problematic by some as an optical beacon must be seen against the bright optical background of a star. In addition, it is presumed that the ETC knows about us and deliberately targets the Earth as is required by the very narrow optical beams. SETI by various means as well as the radio region is discussed by Lemarchand [13].

In general, signals that are searched for in SETI may either be: (i) accidental leakage of signals not intended to be detected by others (e.g. analogs of television broadcasts); or (ii) deliberate beacons. A beacon ought to be easier to detect as it is specifically designed for that purpose. However, even if an ETC wishes to create a beacon for us to observe there are potential problems. For example, a bright beacon requires the expenditure of a large amount of energy. In addition, how will we know where to search for the beacon? Must every one of the  $\sim 10^{11}$  stars in the Galaxy be observed? Targeted searches use a variety of criteria to create a manageable search (e.g. Henry et al. [14]) which may or may not be valid. All sky surveys, which make no such restrictions, however, necessarily suffer from much reduced sensitivity compared to targeted searches.

## 2. SIGNALING IN X-RAYS WITH NEUTRON STARS AND BLACK HOLES

The use of nuclear weapons for signaling via X-rays was considered by Elliott [15]. A large fraction of the energy released by a nuclear weapon is in the form of X-rays and a high-altitude explosion by a sufficient quantity of explosives could produce an attention-attracting pulse. However, as discussed by Fabian [11] a far more powerful signal can be generated by an ETC which has the technology available to exploit the conversion of gravitational

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energy to radiation via a neutron star. Material dropped from a large ( $r \gg 10$  km) distance onto a neutron star will be accelerated to a velocity of order  $0.3c$  and the impact of the material onto the neutron star surface can release 10% of the rest mass as radiation, predominantly as X-rays. The neutron stars that would be used in this way could be either members of interacting binary systems (X-ray binaries) or essentially isolated objects.

Depending on the level of technology possessed by the ETC there may be several broadly defined ways to create an X-ray signal:

- (i) Dump mass onto the neutron star using material such as asteroids or comets if they exist around the star. For comparison, some models to explain the enigmatic  $\gamma$ -ray bursters involve asteroids impacting on an isolated neutron star (see e.g. Wasserman & Salpeter [16]).
- (ii) “Scavenge” material from an accretion disk in an X-ray binary and subsequently release it onto the compact object at desired times.
- (iii) Directly modulate the existing mass transfer process in an X-ray binary. These systems are naturally variable on many time scales and it is hence conceivably easier to modulate energy production in an X-ray binary than, say, a star. In addition, unlike a star where photons must slowly scatter their way out of a deep atmosphere, the photons released by an X-ray binary escape essentially immediately from the system.
- (iv) Obscuration, perhaps using an orbiting screen as suggested by Fabian [11].
- (v) “Recycling” of radiation. A simple scenario would be to pump an X-ray laser [17] utilizing the energy output from the gravitational energy release.

The various techniques need not be exclusive and some combination could plausibly be used.

### 2.1. X-ray Binaries as Beacons

X-ray binaries are broadly divided into two groups: high mass X-ray binaries which consist of a compact object (neutron star or black hole) accreting material by one of several mechanisms from an early-type companion (an O or B type star); and low mass X-ray binaries which are compact objects accreting, typically by Roche lobe overflow, from a G type or later stellar companion. In many cases material does not move directly from the companion to the compact object but, due to angular momentum, goes through an accretion disk. System sizes are typically a few hundred light seconds for high mass systems and a few light seconds for the low mass types. If we assume that a sufficiently technologically advanced civilization can manipulate X-ray emission from an X-ray binary in some way then these sources are potential beacons.

Attractive features of an X-ray binary as a beacon include:

- (i) There are only a small number of X-ray binaries in the Galaxy; for example approximately 100 bright Galactic X-ray sources are listed by Bradt & McClintock [18]. While there is a larger population of transient sources the number of bright persistent sources is small.
- (ii) They are very luminous - up to  $\sim 10^{38}$  ergs  $s^{-1}$ . This has enabled some individual sources in the local group of galaxies to be studied (e.g. Mitsuda et al. [19]).
- (iii) High energy X-rays are not readily absorbed by the interstellar medium unlike the case, for example, of an

optical signal.

(iv) X-rays do not suffer from dispersion as would a radio signal. This means that a broad-band pulse can readily be transmitted without an observer having to search many values in “dispersion space.”

(v) Accretion onto a compact object is an extremely effective way to convert rest-mass to energy and has an efficiency of  $\sim 10\%$  (e.g. Ögelman [20]) compared to fusion ( $\sim 0.1\%$ ). In addition, gravitational energy can be extracted from material of any chemical composition.

(vi) If X-ray sources are also generally regarded as “interesting” by scientifically curious civilizations then such a beacon is likely to be extensively observed.

If the compact object is a neutron star then releasing material onto this object can result in the prompt production of X-rays. However, in the case of a black hole there is no solid surface and so material can only release energy via an accretion disk.

### 2.2. Isolated Neutron Stars

While isolated neutron stars could also be used as a beacon if an ETC deliberately dumps mass onto it, this technique might have disadvantages compared to exploiting natural X-ray binaries:

- (i) The neutron star is not naturally a highly luminous X-ray emitter for a long period and hence is less likely to be observed. Although young short period isolated pulsars are luminous they are comparatively short lived. There is also a much larger number of isolated neutron stars than luminous X-ray binaries in the Galaxy (maybe  $10^8$ – $10^9$  e.g. Paczyński 1990 [21], Blaes & Madau [22]) which gives the same “needle in a haystack” problem as standard radio SETI.
- (ii) There is less likely to be an extensive supply of “fuel” to dump onto the neutron star. The options of accretion disk material extraction or direct modulation are not available.
- (iii) The neutron star does not typically provide the natural copious energy generation that might be of intrinsic value. The energy output of an X-ray binary can be more than  $10^4$  times the total luminosity of the Sun and the ETC would hence lie between type II and type III in the classification scheme of Kardashev [23].

An advantage of isolated neutron stars, however, is that there are far more of these in the Galaxy than X-ray binaries which makes them far more accessible to an ETC. At one point it was popular to consider that  $\gamma$ -ray bursters originated from isolated neutron stars. This would have made these candidate SETI beacons under the models discussed here. However, the isotropic source distribution found by the Compton Gamma Ray Observatory (CGRO) (e.g. Briggs [24]) has caused many to abandon the single neutron star hypothesis and instead place these objects at cosmological distances and to invoke more energetic scenarios such as coalescing neutron star binaries (see e.g. Lipunov et al. [25]).

If we are to find intermittent emission from an isolated neutron star then some type of “all sky” X-ray detector is required. The properties of a number of past, present and planned experiments are listed in Table 1. Detailed observations of a new source can typically be done with greater sensitivity with a pointed experiment once it has been discovered with an all sky detector. All Sky Mon-

itors (ASMs) typically consist of large field of view instruments with moderate spatial resolution that scan a large fraction of the sky with some duty cycle.

### 2.3. *Creating a Beacon*

This use of a natural beacon that is not located at the ETC's "home" requires that it is sufficiently benevolent and/or foresighted to send a probe to an X-ray source. If travel speed is sub-luminal this places constraints on the life times of natural beacons that can be exploited. For example, if a probe travels at  $0.1\%c$  to reach an X-ray binary which is perhaps located 10,000 light years away, then the natural source must have a lifetime of at least  $\sim 10^7$  years to make this worthwhile. High mass X-ray binaries with lifetimes of  $\sim 10^6$  years (e.g. Verbunt [26]) would thus perhaps be less likely to be good targets. However, low mass X-ray binaries, which may have ages in excess of  $10^9$  years, could make much better candidates. The unusual system Hercules X-1, which possesses some properties of both high and low mass systems (see e.g. Bradt & McClintock [18]), is also thought to be relatively old and is thus also a candidate. For a journey of this distance some type of self-replicating ("von Neumann") probe may be required [27]. If a long travel time is indeed required then, to make this worthwhile, the beacon itself might also be expected to have a very long lifetime. The foresight to create such a beacon is on a grander scale than, but perhaps philosophically comparable to, the plaques which have been placed on the Voyager 1 and 2, and Pioneer 10 and 11 probes. The long lifetimes of low mass X-ray binaries might also be attractive to a civilization which desires some type of enduring monument to its existence (compare, for example, to ancient Egyptian pyramids). The low mass X-ray binaries also exhibit a wide range of, apparently natural, variability such as quasi-periodic oscillations and bursts which are causing their temporal variability to be studied in detail. Restricting targets to low mass neutron star X-ray binaries would reduce still further the number of potential beacons to be investigated. However, this would certainly be too restrictive given the small gain in efficiency compared to investigating all X-ray binaries.

If the ETC is only capable of relatively limited low intensity modulation of X-ray emission it may choose to do so at times when the "normal" emission is at relatively low levels in these naturally variable systems. Conversely, if the ETC is capable of triggering transient sources to go into outburst then large outbursts from binaries should be observed in detail (as they are likely to be anyway). A hint that such an amplification mechanism might be possible comes from accretion disks instability models of transients which show that a state change in a small region of a disk can rapidly spread to the rest of the disk (e.g. Cannizzo [28]) and hence a small change could be amplified. Another situation where a small change in the input results in a large change in the output is where mass accretion rate is just below the value required to overcome the centrifugal barrier to accretion caused by the strong magnetic field of a rotating neutron star [29].

### 3. TYPES OF SIGNAL

A beacon might consist of three components:

Type - I: A "look at me" very strong signal of low or zero

artificial signal content.

Type - II: A "carrier" signal indicating we should look further.

Type - III: A high information capacity signal.

For an X-ray binary these three types of signal might correspond to:

- (i) The natural variable X-ray emission.
- (ii) Some type of artificial signal indicating the presence of intelligence. For example this might be the first hundred digits of the number  $\pi$  pulse encoded in binary. If only a comparatively weak signal can be generated then it would be especially advantageous to repeat this in a highly periodic way to increase the possibility of detection.
- (iii) The high information content signal might either be in the X-ray band or could be in another wave band, such as radio, where it might be easier to create a high telemetry rate signal. If in the X-ray band, the signal might be less blatant than the Type - II signal, for example it might utilize one or more narrow energy bands. For example, using the "recycling" technique.

### 4. DISADVANTAGES OF X-RAYS

Communication via X-rays does, naturally, suffer from limitations. For example, individual X-ray photons have a large amount of energy and communication rates are hence set by the number of photons that can be detected rather than the frequency of the X-rays. In addition the mass-dumping technique does not create a narrow energy band signal, unlike most radio or optical transmission techniques, which reduces the signal-to-noise level. However, neither of these are severe problems, particularly for Type - I and Type - II signals where it might be preferable to send a broad band signal when sufficient energy is available to ensure that it is detected.

An additional difficulty with X-ray observations is that they must be conducted from space. While, in itself, this is not a major problem, it does typically result in a restriction on data telemetry rates compared to an entirely ground-based system. High telemetry rates will be produced when both high spectral and high temporal resolutions are required. This problem could be alleviated by searches for signals on board the spacecraft by a sufficiently powerful onboard computer - the raw data itself is not telemetered. An extension of this would be to have a high data rate connection to a space station where the data are stored and/or processed.

### 5. HIGH TIME RESOLUTION X-RAY OBSERVATIONS

If significant artificial modulation of emission from X-ray binaries exists why has it not yet been seen? Fabian [11] claimed that signals that could be seen with simple detectors could relatively easily be produced. While astrophysical X-ray data are not typically investigated for the presence of artificial signals, they are often subjected to a variety of timing analyses such as performing Fourier Transforms which can reveal modulation such as a periodic signal. Although we assume that the ETC is benevolent, an entity that has sufficient foresight to create a very long lasting beacon may not necessarily create a signal that can be detected with the crudest X-ray detectors: X-ray astronomy is a young subject and extra-solar X-ray sources have only been studied since 1962 [30]. The signal may simply be too weak for us to

have detected so far; we cannot determine *a priori* how much of the emission from an X-ray binary might be modulated by a highly advanced civilization. However, an intriguing possibility may be that we are about to open new ranges of parameter space which could contain some type of signal. This is based on the possibility that Type II or III signals may be modulated comparatively rapidly and/or utilize a narrow energy band.

The Rossi X-ray Timing Explorer (RXTE; [31]) was launched in late 1995. While the main Proportional Counter Array (PCA) detector will offer several improvements over previous satellites in terms of a large collecting area ( $7000\text{cm}^2$ ) and a reasonable telemetry rate (mean of  $\sim 40$  kbps with a maximum rate of 512 kbps for short periods) the significant new regime of parameter space that will be opened is for very rapid variability. The PCA consists of five separate proportional counters; individual X-ray photons can be time-tagged to  $1\mu\text{s}$  accuracy and each counter has an independent dead time of approximately  $10\mu\text{s}$ . XTE hence offers the potential to explore sub-millisecond down to microsecond timing not readily accessible to previous X-ray satellites. One driving force behind including this high time resolution capability is to study rapid variability in black hole X-ray binaries such as Cygnus X-1 [32]. The RXTE PCA is compared to some other X-ray missions in Table 2.

Rapid modulation might be employed by an ETC for several reasons. For example, the more rapid the variability, the greater the telemetry rate that results, this could be valuable for Type - II or III signals. Rapid variability may also be advantageous if, on these timescales, there is much less natural signal. For example the minimum rotation period of a neutron star is of order 1 millisecond as is the period of a Keplerian orbit at a neutron star surface. Observations of many systems show the presence of low-frequency timing noise which again implies rapid modulation could be advantageous. Natural quasi-periodic signals at frequencies up to at least kHz frequencies have been detected [33] suggesting artificial modulation frequencies at least this high should be used.

Theoretical investigations of natural emission from blobs falling on neutron stars show X-rays can be released which are modulated on microsecond timescales [34]. Hence, there appears to be no compelling reason that artificial modulation on the same microsecond time scale could not also be produced. A Type - II signal might well be periodic on some time scale and could perhaps be detected as a byproduct of searches that are made to detect the rotation periods of neutron stars in low mass X-ray binaries.

## 6. HIGH SPECTRAL RESOLUTION X-RAY OBSERVATIONS

Currently being planned are at least two X-ray satellites which will provide a combination of high spectral resolution, potentially high temporal resolution, and reasonable collecting areas. These are the Japan/US mission Astro-E, which is scheduled for launch in 1999, and NASA's HTXS (High Throughput X-ray Spectrometer) which is currently in a design phase. The drive for higher spectral resolution comes from a desire to study in detail emission lines such as those from iron in the 6 – 7 keV range as well as others at lower energies. These significantly improved energy resolutions are being achieved by

exploiting devices such as micro-calorimeters (e.g. Moseley et al. [35]) and superconducting tunnel junctions as X-ray detectors [36, 37].

If the ETC is capable of more sophisticated modulation of X-rays, such as confining a signal to a narrow energy band by, for example, using an X-ray laser this will also make it less likely that we would have detected such a signal especially given the very limited energy resolution of current X-ray detectors. Proportional counters, for example, have resolutions of  $\sim 20\%$  at 7 keV while CCD detectors such as those on ASCA, which have a factor  $\sim 10$  better energy resolution, are often used with time resolutions of seconds [38]. These new detectors thus have the potential to significantly expand still further the range of parameter space through which X-ray SETI can be performed.

## 7. CONCLUSION

The development of new detectors continues to expand the parameter space over which we can perform X-ray SETI. Further, in a somewhat similar philosophy to that adopted by SERENDIP [8] in that SETI does not affect regular astrophysical observations, all high time and/or spectral resolution X-ray observations of X-ray binaries can be investigated for unusual signals. The advantage over SERENDIP is that not even any additional hardware is required. Rapid periodic signals during short “bursts” during otherwise low level emission from an X-ray binary could be candidate signals from an ETC. Alternatively, if the ETC can trigger transient outbursts then high time resolution observations of these should be made. There are already in place several “Target of Opportunity” programs to undertake such observations of transients that are detected with the All Sky Monitor experiment on XTE. Other X-ray astronomy satellites that are being planned will also offer significantly enhanced spectral resolution which will open yet another parameter regime. As data from current and future X-ray missions enter public archives it may be profitable to perform systematic searches on all data for pulsed “narrow” energy band signals. While a coherent pulsed signal does not, on its own, guarantee that artificial modulation is present, such signals, especially those with periods less than the minimum rotation period of a neutron star, should be investigated in greater detail.

Including bright X-ray sources in radio and other targeted searches may also be worthwhile. For example, the ETC might construct a higher information capacity optical or radio beacon that will be found once the observer has been alerted to the artificial signals arising from the X-ray source. This Type - III information beacon could make use of the copious long lived energy production from the X-ray binary as its power source.

Given our ignorance of how advanced ETCs might attempt to communicate with us, restricting searches to just the radio portion of the electromagnetic spectrum is likely to be far too limiting. It was once proposed that forests be planted in geometric shapes to communicate to extra-terrestrials that intelligent life exists on the Earth. In just a few hundred years time will it still seem as obvious that radio waves are the best means to communicate across interstellar or intergalactic distances? While it is not claimed here that X-rays are necessarily used by advanced ETCs for communication, it is emphasized that

all potential communication channels should be investigated. As X-ray detector technology improves, in addition to revealing more about the natural high-energy Universe, we are also providing additional channels where evidence of an ETC might be found.

The scenario discussed here and as originally proposed by Fabian [11], while highly speculative, does not require the existence of numerous long-lived civilizations in the Galaxy, neither is it necessarily required that a large fraction of the Galaxy has been colonized. What is required, however, is that, at some time in the history of the Galaxy a civilization existed with the desire and

technological capability to create a durable beacon. The factor “L” in the Drake equation is not the lifetime of the civilization itself but that of whatever beacon it can create.

One way around the Fermi paradox is the proposal that ETs will not be found everywhere in the Galaxy. Instead they will only be in the “interesting” places (e.g. Shostak [39]). While the Solar System itself might not be regarded as interesting, the comparatively rare luminous neutron star and black hole binary systems may be more attractive places.

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**Table 1**  
Selected X-ray Astronomy Satellites - All Sky Monitors

Satellite/Instrument	Band Pass (keV)	Angular Resolution (degrees)	Sensitivity ( $\mu\text{Jy}$ )	Mission Dates
Vela 5B (XC)	3-12	6.1	400	1969 - 1979
Ariel V (ASM)	3-6	10	170	1974 - 1980
Ginga (ASM)	2-20	0.2	50	1987 - 1991
Granat (Watch)	6-180	2	100	1989 - ?
CGRO (BATSE) <sup>1</sup>	20-600	5	(a)	1991 - ?
XTE (ASM)	2-10	6	25	1995 - ?
SAX (WFC) <sup>2</sup>	2-30	0.1	1	1996 - ?
Spectrum-X/ $\gamma$ (MOXE)	2-25	1.1	7	1997? - ?

Notes: taken in part from In't Zand, Friedhorsky & Moss [40], and references therein. Also, (1) Horack [41], (2) Jager et al. [42]. (a):  $3 \times 10^{-8}$  ergs  $\text{cm}^{-2}$  for a one second burst. Angular resolutions are worst cases for a particular instrument.

**Table 2**  
Selected X-ray Astronomy Satellites - Pointed Experiments

Satellite/Instrument	Time Resolution ( $\mu\text{s}$ )	Spectral Resolution $E/\Delta E$	Collecting Area $\text{cm}^2$	Mission Dates
Ginga (LAC)	980	6	4000	1987 - 1991
ASCA (SIS)	16,000	50	$250 \times 2$	1993 - ?
XTE (PCA)	1	6	7000	1995 - ?
Astro E (XRS)	20?	670	400	2000? - ?
HTXS	?	$\sim 10000?$	2000?	$> 2000?$ - ?

Notes: Spectral resolutions are approximate and are at 6.7 keV. Time resolutions are the best available for an instrument and are not necessarily generally used. Extensive information on X-ray astronomy missions can be found in Bradt, Ohashi & Pounds [43].